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VESSEL TRAFFIC SERVICES TRAFFIC MANAGEMENT SUMMARY REPORT

E. Gressler, N. Meador

2 July 1981

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Prepared for:

U.S. DEPARTMENT OF TRANSPORTATION
United States Coast Guard
Office of Research and Development
Washington, D.C. 20590

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
[illegible]	AD [illegible]	
4. Title and Subtitle		5. Report Date
[illegible] Traffic Management Summary [illegible]		July 198[illegible]
		6. Performing Organization Code
		8. Performing Organization Report No.
7. Author(s)		ASEC R-8[illegible]
[illegible] Meader		
9. Performing Organization Name and Address		10. Work Unit No. (TRAIS)
[illegible] Systems Engineering Corporation [illegible]		11. Contract or Grant No.
[illegible]		DT[illegible]
[illegible] Massachusetts [illegible]		13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address		March 1981-May 198[illegible]
Office of Research and Development [illegible]		
[illegible] Coast Guard		
Washington [illegible]		14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This report presents an overview of the Vessel Traffic Services Management Study performed by ASEC. The objective of the report is to present the results of the study concisely for readers who may not have a technical background in VTS.

The major topics related to traffic management, safety, capacity, and measures of effectiveness, were defined, developed and refined over the course of the Traffic Management Study. The Summary Report has combined these development steps into one integrated discussion for each topic. The Vessel Traffic Simulation Model has been emphasized since it was one of the major accomplishments of the study.

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Dist

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17. Key Words

Vessel Traffic Management, Marine Safety, Port Traffic Capacity, Measures of Effectiveness, Computer Simulation, Modeling, Hazard Potential, Vessel Maneuvering

18. Distribution Statement

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED		

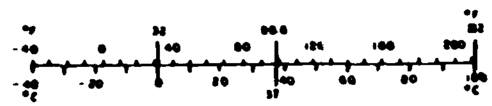
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



ASECR 81-133

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E. Grassler
N. Meader

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1. INTRODUCTION

1.1 PURPOSE

This report summarizes the Vessel Traffic Services Traffic Management Study. The project was part of the Coast Guard's research and development in Vessel Traffic Services (VTS) and was aimed at developing a methodology for assessing the impact of traffic management on port safety and capacity. The methodology developed centered on a vessel traffic simulation which models vessel traffic under a broad range of conditions. Key parameters such as port characteristics, traffic management techniques, environmental factors, traffic level, traffic density, vessel types and traffic routes within the port can be varied as necessary for a simulation. The model provides measures of safety and capacity and permits a comparison of these factors when the basic parameters are varied.

The role of simulation in VTS research and development is discussed with emphasis on the Vessel Traffic Simulation Model developed during the study. Recommendations for the application of the model are presented.

No special knowledge of either Vessel Traffic Services or simulation techniques on the part of the reader is presupposed. Both topics are sufficiently addressed in the report to make the objectives and methods of the study understandable. Much of the supporting documentation and data for the material presented is identified in the bibliography.

1.2 BACKGROUND

A major objective of Vessel Traffic Services is to reduce the number of accidents in a harbor. Vessel Traffic Services are utilized in many foreign and American ports to cope with increasing demands on

restricted waters by larger merchant vessels and greater traffic volumes.

The main impetus for VTS in the U.S. lies in the Ports and Waterways Safety Act of 1972, which authorizes the Coast Guard to "...establish, operate, and maintain vessel traffic services and systems for ports, harbors, and other waters subject to congested vessel traffic...". The U.S. Coast Guard operates all official VTS in the United States.

In the United States, VTS are presently operating in New Orleans, Houston - Galveston, San Francisco, Puget Sound, Valdez, Alaska and New York. These installations rely primarily on Very High Frequency (VHF) ship-to-shore communications to monitor vessel traffic. Vessels report their positions, approximate speeds and destinations at established check points and in return are provided with traffic advisories by the Vessel Traffic Center (VTC). Shore-based surveillance radars or closed-circuit television are used in certain ports to supplement the check-point information in congested or hazardous areas. The VTC maintains situation displays, either manually or with computer assistance; vessel positions between check-points are obtained from dead-reckoning and by monitoring bridge-to-bridge communications. Participation in the VTS in the ports of Valdez and Puget Sound is mandatory; in the other ports, participation is voluntary. The Coast Guard has successfully encouraged participation in VTS in ports where VTS is voluntary. Vessels required to participate are usually ships of 300 gross tons or larger and vessels carrying passage for hire. Pleasure boats and smaller commercial vessels such as fishing boats do not usually participate in a VTS. The Vessel Traffic Center is aware of special conditions involving these types of vessels (such as regattas or fishing activities in or near shipping lanes) and advises vessels of these situations as necessary.

Vessel Traffic Services in the U.S. do not attempt to manage traffic. Furthermore, the extent to which some form of traffic management, as might be exercised with more sophisticated VTS capabilities than presently exist, could prevent marine accidents has not been fully

determined. The types of accidents that are preventable have not been completely identified. International experience with VTS and qualitative analyses have indicated that appropriate traffic management can prevent some traffic accidents through the elimination of inherently hazardous circumstances. The objective of the VTS Traffic Management Study was to provide a way to assess the potential for traffic management to prevent or reduce marine accidents in ports and harbors.

The VTS Traffic Management Study consisted of five distinct phases. The first phase--definition--consisted of establishing the VTS data base, defining hazards to navigation and traffic capacity, and identifying techniques for traffic management. Measures to evaluate the effectiveness of traffic management techniques in terms of safety and capacity were developed. The second phase--development--consisted of developing techniques to calculate hazard potential and traffic capacity. The Vessel Traffic Simulation Model was developed during this phase together with algorithms to calculate safety and capacity. The third phase--evaluation--consisted of identifying trade-offs between safety and capacity. Methods for comparing cost and effectiveness of traffic management alternatives were evaluated. The fourth phase--testing--consisted of establishing that the model reasonably simulates actual vessel movements.

The fifth phase--further testing and verification of the Vessel Traffic Simulation Model--consisted of investigating extended applications of the model. Stochastic variability in certain decision-making functions of the model was introduced and a model for towboat traffic on the Mississippi River was devised.

1.3 VESSEL TRAFFIC SIMULATION MODEL

The major result of the study was a Vessel Traffic Simulation Model. This computerized model simulates the movements of vessels in ports by maintaining a record of the geographic position of each vessel.

A vessel's recorded position is changed by the ship's own motion and by currents subject to physical laws. Vessels follow flexible pre-planned routes and make appropriate maneuvers to avoid collisions when encountering other vessels. Second order response functions are used to model the dynamics of the vessels so that turns and changes in speed are continuous and realistic. The model may be set up for any port by defining the harbor boundaries and a set of reference track lines which establishes the vessel traffic route structure. Any number of a large variety of vessel types and sizes may be simulated. Vessel parameters including maneuvering characteristics and routes are specified as input to the program. Other inputs include environmental factors including water current and visibility.

When a ship encounters another ship, or a fixed object, the model invokes conflict resolution logic that determines the burdened vessel's maneuvers. The general procedures for conflict resolution are:

1) Crossing -- the burdened vessel will alter its speed to give free passage to the privileged vessel.

2) Meeting -- the burdened vessel will alter its course in such a way as to pass the privileged vessel at a safe distance. In this case, a heading change is made and held until the safe distance is reached. The vessel then returns to the original heading but maintains the new separation distance.

3) Overtaking -- a vessel will attempt to overtake another vessel only if there is sufficient room on either the port or starboard sides so that the overtaking will be done at a safe distance. If overtaking is possible, the vessel will alter its heading until the safe distance is attained, and then return to the original heading and complete the overtaking maneuver. If overtaking is not possible, the vessel will reduce its speed to match that of the predecessor and continue on its planned course.

The model generates vessel track histories for each vessel from its starting point anywhere in the port to its destination. When all vessels have completed their transits, significant events which occurred during the simulation are summarized. These events include:

1) Time of Arrival of Vessel - the time at which a vessel is first included in the simulation. This may be at any time during the exercise.

2) Time of Departure of Vessel - the time that a vessel reaches its destination and is removed from the simulation.

3) Encounters - situations when two or more vessels meet and at least one maneuvers to avoid a conflict.

4) Very Close Encounters - encounters in which the closest point of approach between the vessels is less than a pre-defined safe threshold.

5) Extreme Maneuvers - events in which a simulated vessel uses maximum rudder or maximum deceleration. Note that these maximums apply to simulated vessels and not real world methods of maneuvering.

6) Port Capacity - the practical maximum rate of flow that the port configuration can safely sustain.

7) Mass Accident Coefficient - a measure of port safety which relates traffic volume to risk of accident.

2. HAZARDS TO NAVIGATION AND HAZARD POTENTIAL

In this part of the VTS Traffic Management Study, the concept of a hazard to navigation was defined and categorized. Methods to calculate hazard potential were then developed.

2.1 IDENTIFICATION, DEFINITION AND CLASSIFICATION OF HAZARDS

The definition of a hazard to navigation is basic to analyzing accidents and assessing the causes of accidents. A definition of a hazard which can be applied to measuring port safety was derived from the analysis of historical marine casualty data. This definition is not meant to be absolute, but rather to provide a frame of reference for addressing the main results of the study. The definition provided is therefore intended to be a working definition of a hazard.

A hazard to navigation is anything that causes undesired evasive maneuvers or prevents required evasive maneuvers. This definition introduces two concepts -- space and time -- which relate hazards to causes of accidents. Hazards to navigation may restrict the freedom to maneuver or the time available to execute maneuvering decisions. The area about a vessel for maneuvering space and reaction time which must be clear of other vessels, obstructions and the shoreline is called the effective domain of a vessel. When the effective domain is violated, an evasive maneuver is required. The effective domain will be discussed in detail in section 3 of this report.

2.1.1 Casualty Data Sources, Causes and Contributing Factors

Data from two principal casualty information sources were analyzed to identify primary and contributing causes of accidents.

Marine Vessel Casualty Reports

The primary source of casualty information used in the analysis was the Marine Vessel Casualty Reports (MVCR) data base prepared by the U.S. Coast Guard from official Casualty Reports (Reference [illegible]). The MVCR data shows the primary cause of an accident as established by official investigators. Computer printouts were obtained for the years [illegible] (in-complete), 1971-1974, and 1975 (incomplete) for the New York/New Jersey, San Francisco and Puget Sound port areas. These three regions were selected on the basis of the range of traffic characteristics and the number of casualties they represent. The information of primary interest extracted from the MVCR data was nature of the casualty, primary cause, contributing factors and the environmental conditions at the time of the accident.

An analysis by type of accident and the frequency of accident types by port area was performed. A summary of the results of this analysis is shown in Table 2-1. The analysis indicated that the frequency of accidents and types of accidents are related to the geographic, environmental and traffic characteristics of the specific port. In the New York/New Jersey port area, collisions and groundings were equally frequent while rammings were less frequent. San Francisco had equal numbers of groundings and rammings but a higher number of collisions. The deep water characteristics of Puget Sound are evidenced by that area having the least number of groundings of the three port areas examined.

The collision data for the ports examined also indicate that the type of collision is related to the prevalent traffic patterns of a port. For example, New York/New Jersey, which is characterized by numerous intersections and restricted maneuvering space, has the highest percentage of meeting collisions. Puget Sound, which has inbound/outbound lanes of a traffic separation scheme, is highest in overtaking collisions.

TABLE [illegible]

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]

[illegible]

[illegible]

[illegible] independent [illegible] are the most [illegible] case, [illegible] given [illegible] is the next most [illegible]

TABLE 2-2

PRIMARY CAUSE BREAKDOWN

MVCR DATA (1970-1975)

81-0710V

PRIMARY CAUSES	NEW YORK NEW JERSEY		SAN FRANCISCO		PUGET SOUND	
VIOLATION OF REGULATIONS	30	(6%)	11	(8.3%)	13	(12.9%)
PILOT ERROR	93	(18.7%)	31	(23.5%)	14	(13.9%)
JUDGEMENT ERROR	204	(41%)	52	(39.4%)	40	(39.6%)
ADVERSE WEATHER	24	(4.8%)	8	(6.1%)	3	(3.0%)
UNUSUAL CURRENTS	9	(1.8%)	0		3	(3.0%)
BANK EFFECTS	6	(1.2%)	0		0	
UNCHARTED SHOAL	9	(1.8%)	3	(2.3%)	1	(1.0%)
RESTRICTED MANEUVERING ROOM	6	(1.2%)	2	(1.5%)	0	
STRUCTURAL FAILURE	32	(6.4%)	0		5	(5.0%)
EQUIPMENT FAILURE	37	(7.4%)	11	(8.3%)	11	(10.9%)
FAULT - OTHER VESSEL	6	(1.2%)	0		0	
EVASIVE MANEUVER RESULTED IN CASUALTY	13	(2.6%)	0		1	(1.0%)
FLOATING SUBMERGED DEBRIS	40	(8.1%)	8	(6.1%)	5	(5.0%)
INADEQUATE TUG CONTROL	5	(1.0%)	1	(0.8%)	1	(1.0%)
UNKNOWN	18	(3.6%)	5	(3.4%)	4	(4.0%)
TOTAL CASUALTIES	532		132		101	

2.2 CALCULATION OF HAZARD POTENTIAL

Two separate methods of calculating hazard potential were developed in the VTS Management Study. First, simulation modeling was used and emphasis was on conflicts between vessels. Second, a mass accident theory was developed which concentrated on characterizing the statistical relationship between accident frequency and vessel traffic volume in a port.

2.2.1 Simulation Modeling Methods

Marine accidents in a port are relatively rare compared to the number of vessel transits. Because of the scarcity of data, hazard potential was evaluated by using reliable simulation to determine the types of events which could result in an accident. The Vessel Traffic Simulation Model was used to simulate vessels maneuvering to avoid each other in potentially hazardous situations.

The four means of calculating hazard potential are described below.

<u>Encounters</u>

An encounter is defined as a meeting between two vessels in which one of the vessels must maneuver to avoid a conflict. Encounters are normal meeting situations between vessels. In terms of the simulation logic, an encounter has occurred whenever one vessel must change heading or speed to avoid a second vessel. A vessel will remain in an encounter status as long as the maneuver is continued.

The model determines the:

1) Number of encounters for each ship
2) Duration of each encounter
3) Total number of encounters.

Also, for each encounter, the model determines the:

1) Type of encounter
2) Ships involved
3) Positions of ships
4) Rate of turn of each ship
5) Acceleration/deceleration of each ship.

Very Close Encounters

A very close encounter is defined as an encounter situation where the distance between the two vessels is less than a prescribed threshold. In the model, the threshold is proportional to the sum of the lengths of the two vessels. The constant of proportionality is specified by the user as an input to the program.

Very close encounters are situations where the vessels are maneuvering in close quarters. In the real world these would be considered especially dangerous situations. It should be noted that a very close encounter does not occur unless the vessels are already in an encounter. If, for example, two vessels are sailing in opposite directions on different reference track lines and the model logic causes them to ignore each other so that neither maneuvers to avoid the other, they will not be recorded as having an encounter. This permits simulating real world situations such as passing in narrow channels which is often a normal occurrence.

The model determines the:

1) Number of very close encounters per ship
2) Total number of very close encounters for the simulation run.

Also, for each very close encounter, the model determines the:

1) Type of encounter when there is a very close encounter
2) Ships involved

3) Positions of ships

4) Heading and speed of each ship

5) Distance between ships

6) Overlap of effective domains

7) Time duration for each very close encounter.

Extreme Maneuvers

An extreme maneuver is a maneuver which causes a simulated vessel to turn or decelerate at its maximum physical limit. The model computes a course or speed change in two steps. For a course change, a rudder angle setting is derived from the desired heading, the present heading, the present rate of turn and the ship dynamics. The rudder angle is then converted to a rate of turn proportional to the rudder angle. A similar process is performed for speed changes with propeller shaft RPM as the intermediate step. Both the rudder angle and the propeller shaft RPM values are bounded in the model; the propeller shaft RPM may be negative to simulate reverse thrust.

An extreme maneuver occurs when either the rudder angle or propeller shaft RPM of a simulated vessel is set at a maximum value and the vessel is in an encounter situation. The model will select only values sufficiently large to cause a vessel to avoid a conflict; therefore not all conflicts will result in extreme maneuvers.

2.2.2 Mass Accident Distribution Theory

An analysis of historical data on traffic volume, number of cargo tons, and accidents for selected ports showed that collisions per million cargo tons was the only statistic which remained relatively trendless over a long period of time during which numbers of vessels, collisions, cargo tons, etc. grew significantly. This relationship led to the conclusion that an accident distribution function for which the risk of an accident was dependent on the mass (in gross tons, displacement, etc.)

of the vessel could be developed. A strong relationship appeared to exist between vessel mass and the risk of an accident. It was determined that the draft of a vessel is directly related to the mass of a vessel. The parameter defining this relationship was called the mass accident coefficient.

The mass accident coefficient was found to vary significantly among vessel classes and ports for those ports investigated. The mass accident coefficient is a directly proportional measure of the risk of an accident in a specific port for a given type of vessel. Further data analysis will be required, however, to establish the statistical validity of this theory.

The mass accident coefficient was also found to exhibit growth characteristics over time. This was shown for Tokyo Bay for which data was analyzed for the years 1958-1968. In this port the data was sufficiently large to permit a yearly calculation of the mass accident coefficient. A function was derived representing the growth of the mass accident coefficient that potentially could predict the number of accidents for future traffic volumes.

2.3 MEASURES OF SAFETY

The measures utilized to evaluate port safety included the:

1) Number of encounters and very close encounters
2) Duration of encounters and very close encounters
3) Number of encounters and very close encounters by vessel draft
4) Extreme maneuvers by vessel draft
5) The mass accident coefficient.

Each of these measures of safety, discussed below, is calculated by the simulation model.

Number of Encounters and Very Close Encounters

Although vessel encounters are normal events for vessels maneuvering in restricted waters, it is evident that the risk of a collision between vessels increases as the number of encounters increases. The number of encounters that a vessel has, therefore, is an elementary indicator of the vessel risk potential.

The number of very close encounters for each vessel is a stronger measure of risk potential. Since each very close encounter is also an encounter, the set of very close encounters forms a subset of the set of encounters. It was found that the number of very close encounters, expressed as a percentage of total encounters, varies considerably with the port situation. Very close encounters represent a significant proportion of all encounters when, because of (simulated) limited visibility or restricted maneuvering space, encounters do not occur until vessels are quite close. In these situations an encounter quickly becomes a very close encounter.

Duration of Encounters and Very Close Encounters

The duration of an encounter or very close encounter is the time interval from the beginning of an encounter to the time when the situation is resolved, either by evasive maneuvers, turn-offs, or removal of a vessel from the system. The duration is an important measure of risk potential since it adds information about the encounter situation which is not available from a simple count of encounters.

Encounters and Very Close Encounters by Vessel Draft

In order to present statistics on encounters and very close encounters by types or classes of vessels, it was necessary to identify a single parameter which could characterize vessels. Vessel draft was chosen since the mass accident distribution theory suggested a

correlation between vessel draft and risk potential. Furthermore, there are theoretical (non-linear) relationships between draft and other parameters such as length, beam and gross tonnage. Therefore, data concerning encounters and very close encounters is presented in terms of the drafts of the vessels involved.

Extreme Maneuvers by Draft

The number of extreme maneuvers used by vessels provides a measure of risk potential for a port situation. Extreme maneuvers reflect situations where conflicts must be resolved quickly after conflict detection. These situations might occur because the time for conflict resolution is reduced by simulated low visibility or by traffic congestion where vessels move from encounter to encounter in rapid succession.

Mass Accident Coefficient

The mass accident coefficient is calculated for each simulation run. The theoretical derivation of this parameter indicates that it may provide a measure of the relative safety of a port under varying conditions.

3. CAPACITY

3.1 DEFINITION OF CAPACITY AND EFFECTIVE DOMAIN

Capacity is a measure either of the theoretical maximum flow of vessels through a given area per unit of time (basic capacity) or of the reduced flow resulting from less than optimum conditions (practical capacity). For the concept of capacity to be useful, it must be defined in terms of safe vessel separation. For this purpose the concept of an effective domain is appropriate.

As defined earlier, the effective domain of a vessel is an area around a vessel which remains clear of other vessels or obstructions. If the effective domain is penetrated then evasive maneuvers are required and a risk of accident exists. Empirical surveys of vessel traffic (Reference 5) indicate that the effective domain is a semi-ellipse centered on the stern of the vessel and projecting forward. Basic physical laws require that separation along the course direction must relate to vessel size and speed in a continuous way. The larger or faster the vessel, the larger the safe separation distance. Lateral separation must be large enough that only a mismaneuver would [illegible]. Figure 3-1 shows the effective domain of a vessel [illegible].

The effective domain is a semi-ellipse such that:

1) Semi-major axis projects forward along the velocity vector.

2) Semi-minor axis is of length [illegible] dependent on external factors. These values are taken from traffic surveys.

3) Length of the semi-major axis increases with velocity and mass.

4) Lengths of both axes increase with vessel position uncertainty due to less than ideal conditions.

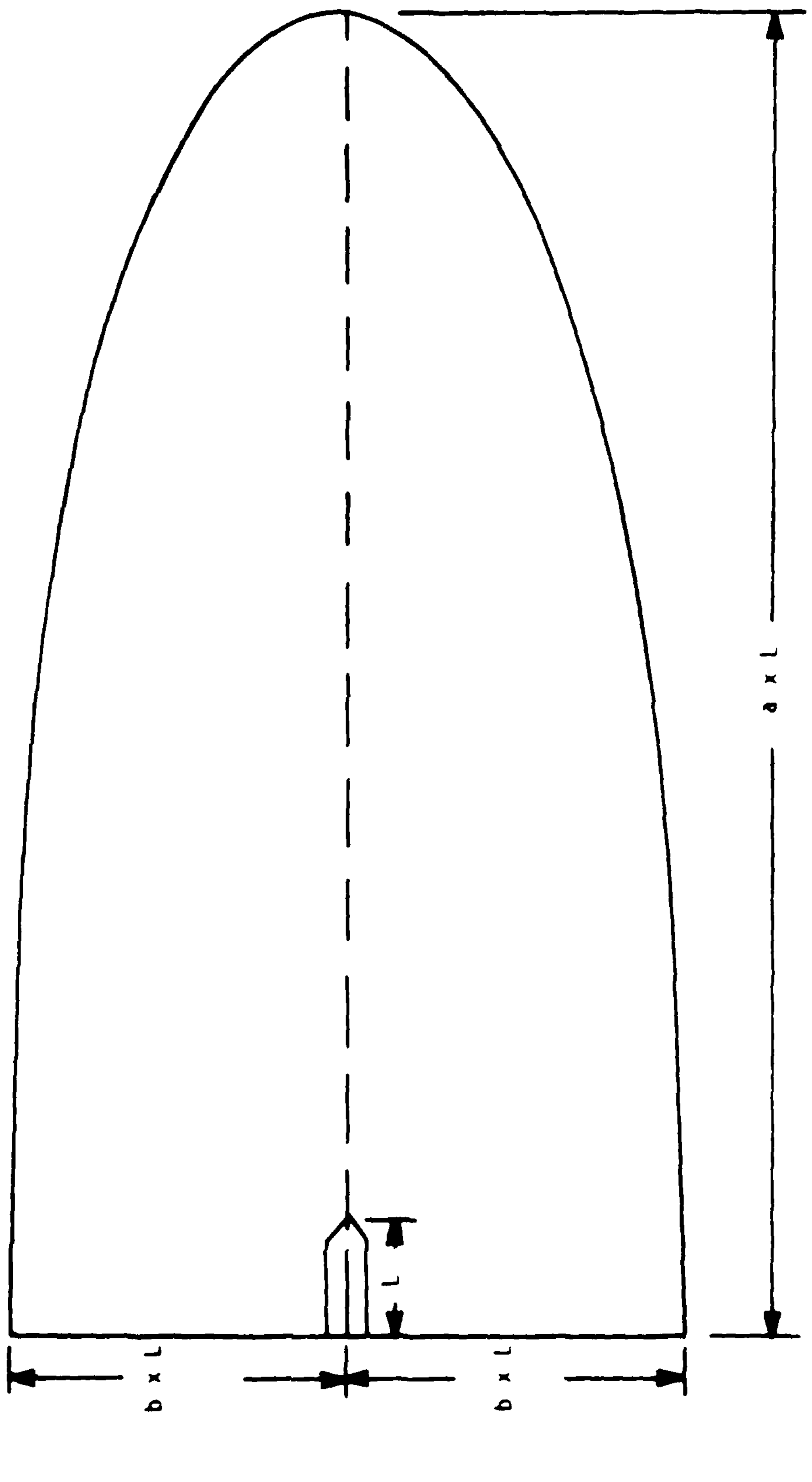

Figure 3-1 Effective Domain for a Vessel of Length L

3.2 TRAFFIC CAPACITY CALCULATION TECHNIQUES

Capacity calculations are divided into two classes. The first class consists of the direct calculations of capacity which establish the number of vessels that a system is capable of handling at any one time. Its simplest formulation is a function of the aggregate of the vessels' effective domains and the navigable harbor area. The second class consists of indirect calculations of capacity which provide an assessment of the effects of varying vessel traffic on the system rather than providing a vessel quantity for the harbor.

3.2.1 Direct Capacity Calculations

Direct measures of capacity are calculated from the total harbor area available to vessel traffic and the effective domains required by vessels to maneuver safely within the harbor system. Capacity is first defined for ideal conditions under which the maximum amount of navigable water is utilized. This is the BASIC CAPACITY. Basic capacity is the vessel density multiplied by the width of navigable water multiplied by the vessel speed in the same measure of time. In the limiting case, vessel density is the reciprocal of the domain area. The basic capacity of a harbor is then the number of vessels whose sum of effective domains is equal to the harbor area.

The effects of changing environmental or control conditions will degrade the Basic Capacity to some practical level which makes less than maximum use of available water space, but which keeps vessel risk within acceptable levels. This is the PRACTICAL CAPACITY. Practical capacity is a further refinement of capacity based on the mean effective domain and the physical limitation of the harbor. The direct calculation of practical capacity requires calculating the mean effective domain area available to vessels dependent upon the time period, mean vessel speed, harbor configuration, vessel transits and transit distribution inconsistencies. Once the available effective domain area is determined, the maximum number of attainable transits, practical capacity, is computed.

3.2.2 Indirect Capacity Calculations

As the number of vessels simultaneously transiting a harbor increases, the number of conflicts between vessels will probably increase. At the other extreme, if vessel density is sufficiently low, a ship can proceed through the port without having to maneuver to avoid other ships. As density increases, congestion begins to occur, resulting in conflicts. Port capacity is affected when vessels must alter routes, arrival/departure times or transit times. Therefore various indirect calculations of capacity can be developed based on the frequency of vessel encounters and other interactions.

The simulation events which provide these calculations are:

1) Encounters and very close encounters
2) Extreme maneuvers
3) Transit times

Encounters and Very Close Encounters

Encounters and very close encounters reveal the effects of variations in vessel density. They are more indicative of capacity limits. For example, if vessels are added to the port and no appreciable increase in frequency or duration of these situations occurs, then the capacity of the system is not being taxed. If, however, variations in vessel inputs result in disproportionate changes in the frequency and duration of these situations, then demands on the capacity of the port may be excessive and a reasonable capacity level has been exceeded.

Extreme Maneuvers

An extreme maneuver was defined as a rudder angle setting at its maximum or minimum limit corresponding to a maximum rate of turn or a propeller shaft RPM setting corresponding to the maximum deceleration of a vessel. An extreme maneuver is recorded in the simulation only when a vessel is in a conflict situation. This prevents normal maneuvers using

maximum rudder or screw RPM from being counted as an extreme maneuver unless the vessel is involved in a conflict. An important causal factor in extreme maneuvers is multiple vessel conflicts, a result of increased system loading. The first conflict requires certain heading or speed changes by the burdened vessel. Each additional conflict may require additional heading or speed alterations. To the extent that small variations in vessel traffic result in larger variations in the frequency of extreme maneuvers, the safe capacity of the port is being taxed.

Transit Time Calculations

The transit time of a vessel is the difference between the time it enters the simulation and the time it arrives at its destination. Actual transit time refers to the time required for a vessel to complete its passage when the model uses conflict resolution maneuvers and speed changes whereas baseline transit time is passage time in the absence of conflict resolution. The latter is the optimum for the planned route and speed of the vessel.

If the differences between actual transit times and baseline transit times are small, the capacity of the system is not being taxed. As the difference between the actual transit times and the baseline transit times become larger, it may be inferred that demands on the system capacity have increased. Larger differences indicate an increase in some combination of the following situations:

1) Greater frequency and duration of conflicts in the system, resulting in reduced speeds and increased transit times
2) More multiple vessel conflicts. Additional course modifications and/or speed decreases may be required with each additional conflict.

4. TRAFFIC MANAGEMENT TECHNIQUES

4.1 IDENTIFY AND DEFINE VTS OPERATING MODES

VTS operating modes may be passive or active. In the Passive Mode, a general set of routes is defined along with rules or guidelines to the mariner for navigating his vessel. The burden is on the mariner to safely navigate the routes according to the rules with no additional information from a VTS.

Three categories of active operating modes for VTS include Informing, Hazard Detecting, and Routing. In the Informing Mode, the VTS acquires, organizes and disseminates information that might be useful to mariners. Such information could include local weather conditions, tide and current conditions, presence of hazards to navigation, traffic conditions, etc. A VTS operating in the Informing Mode might issue relevant information at regular intervals over VHF-FM radio and/or at the request of specific vessels.

In the Hazard Detecting Mode, the VTS evaluates traffic information to anticipate potential conflict situations. When a potential conflict is identified, the VTS will contact the involved vessel(s) and issue a warning of the conflict or a directive for avoiding the conflict. A VTS operating in the Hazard Detecting Mode also provides the traffic and navigation information that an Informing Mode VTS disseminates.

A VTS operating in the Routing Mode provides congestion free routing for all vessels to maximize traffic flow while providing the services of an Informing and Hazard Detecting VTS. To accomplish this, the VTS must perform timely analysis of traffic and navigation conditions, identify routes for all vessels, and provide departure and arrival times to ensure that the selected routes will be conflict-free.

The three active operating modes require a facility from which to provide vessel traffic services. The amount and sophistication of the equipment and personnel required to provide services (including surveillance, communications, data processing - automated or manual, display, etc.) increases with the responsibilities of the VTS operating mode.

4.2 IDENTIFY AND DEFINE TRAFFIC MANAGEMENT TECHNIQUES

Within each VTS operating mode, traffic management techniques have been identified that may be used to provide the required vessel traffic services. These eight techniques can be ordered in a hierarchy according to an increasing level of traffic management:

1) Rules of Road
2) Traffic Separation Schemes
3) Navigation Advisories
4) Traffic Advisories
5) Traffic Warnings
6) Conflict Resolution
7) Departure/Arrival Control
8) Route/Speed Assignments

Figure 4-1 indicates those traffic management techniques that may be utilized in each of the four VTS operating modes. As the VTS operating mode is advanced from Passive to Routing, an increasing number of traffic management techniques may be used. Each of the techniques is described below.

Traffic management by the RULES OF THE ROAD includes the use of all existing rules that apply to U.S. ports and harbors and inland waterways, local rules, notices to mariners, available floating and fixed aids to navigation and the channel network that exists in specific ports.

A TRAFFIC SEPARATION SCHEME separates opposing lanes of traffic and may use a separation zone which no vessel is allowed to enter between

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VTS OPERATING MODES / TRAFFIC MANAGEMENT TECHNIQUES	PASSIVE	INFORMING	HAZARD DETECTING	ROUTING
RULES OF THE ROAD	X	X	X	X
TRAFFIC SEPARATION SCHEMES	X	X	X	X
NAVIGATION ADVISORIES		X	X	X
TRAFFIC ADVISORIES		X	X	X
TRAFFIC WARNINGS			X	X
CONFLICT RESOLUTION			X	X
DEPARTURE/ARRIVAL CONTROL				X
ROUTE/SPEED ASSIGNMENTS				X

Figure 4-1 Traffic Management Techniques Used in VTS Operating Modes

the lanes. A separation scheme may also be defined within a one-way lane of traffic to separate vessels by size and draft. The separation schemes can be indicated on navigation charts and implemented with buoys.

These two traffic management techniques can be utilized in a Passive VTS.

In traffic management by NAVIGATION ADVISORIES a VTS issues general environmental and operational information such as local weather conditions and anticipated changes, current and tide conditions and anticipated changes, changes in position or condition of aids to navigation, and the existence of hazards to navigation (such as an uncharted shoal or a reported vessel grounding). This technique requires the VTS to have a central facility with communications to acquire relevant information and to broadcast it to mariners. It does not require any surveillance capability but the approach is improved if mariners contact the VTS immediately to report changes in navigation conditions.

The use of TRAFFIC ADVISORIES is closely related to the previous technique. In addition to providing navigation information, the Vessel Traffic Center (VTC) monitors all participating vessels and issues advisories on traffic conditions throughout the port. The monitoring can be done with reports from mariners (e.g., a Vessel Movement Reporting System (VMRS)) or with the aid of surveillance (e.g., Low Light Level Television (LLTV) or radar) covering specific areas of the port.

The four traffic management techniques described so far can be used by a VTS operating in the Informing Mode. These traffic management techniques are only advisory; and vessels participate on a voluntary basis. The VTS does not take an active part in altering traffic distribution or patterns. A more active role is initiated with the next management technique listed and the level of control exercised by the VTS increases with each of the following traffic management techniques.

In management by TRAFFIC WARNINGS a VTC monitors all participating vessels (and possibly others) and warns specific vessels of potential encounters during the vessel's transit. Although this technique could be implemented through a VMRS, the credibility of the warnings will be greatly increased if they result from active surveillance and analysis on the part of the VTC. Traffic warnings should be based on information that is more accurate than that available with the traffic advisories technique. If a VMRS is employed, therefore, it would be mandatory for all participating vessels to report their arrival, speed, etc. at specified locations, and traffic conditions as they see them. The VTC must process this information in a timely manner in order to predict conflict situations and issue the warnings. This requires some processing capability (manual, automated or some combination) at the VTC. Although he is not <u>required</u> to act on these warnings, the prudent mariner will rely on this information as long as he is assured that the information is more accurate, reliable, and up-to-date than his on-board information.

In CONFLICT RESOLUTION the VTC tracks all participating vessels and other vessels and issues mandatory directives to specific vessels only when a potential conflict has been identified. These directives may involve a change in the vessel's speed, route, course or may require a vessel to anchor. With this technique, the VTC is actively managing traffic in conflict situations.

The six traffic management techniques described above may be employed by a VTS operating in the Hazard Detecting Mode. The additional two management techniques described below may be used by a VTS operating in the Routing Mode.

With DEPARTURE/ARRIVAL CONTROL, The VTC has advance information on vessels intending to enter or leave the port and schedules the arrival and departure of these vessels to minimize potential encounters along the vessel's entire route. In addition, the VTC will track all participating vessels, and possibly other vessels, and issue mandatory directives should a conflict situation occur.

The use of ROUTE AND SPEED ASSIGNMENTS is the highest level of management provided by a VTS. The VTC tracks all vessels and controls the movements of the participating vessels, whether or not a conflict situation exists. It is the responsibility of the VTC to schedule the arrival and departure time of all participating vessels, assign a conflict-free route through each vessel's transit, and assign speeds that are to be maintained along each leg of the vessel's route. While this might seem to be a tremendous amount of "external" control to the mariner, this approach to traffic management could optimize port scheduling, capacity, and traffic flow. Most mariners will gain speedier and safer transits.

5. PORT DESCRIPTION PROCEDURE

Since the Vessel Traffic Simulation Model is designed to simulate real ports, a systematic methodology for collecting and organizing port data is needed. This will form the basis of the simulation data base for the port.

5.1 PURPOSE OF PORT DESCRIPTION

The port description procedure methodically organizes the data base required for the analyses concerning vessel traffic management. Published materials were the primary data sources used in the study; special data collection activities such as traffic surveys were performed only for the detailed analyses of the port of New Orleans.

The Elementary Harbor Unit (EHU) is the basic unit in a harbor in which the shape, shoreline, waterway type, aids to navigation, traffic patterns, vessel types, and environmental characteristics are as uniform as possible. The EHU is used to identify the salient characteristic of a port and provides an efficient means of breaking down the port into smaller units. Most ports are not homogeneous, but vary in types of waterways, vessel traffic composition, port facilities and other features. Smaller subsections of the port (EHUs), which are homogeneous in the salient characteristics, can be aggregated to portray the harbor. The EHU concept permits a complex port to be described in terms of a set of data elements which are consistent within that EHU; the total port is then the aggregate of EHUs defined for that port.

5.2 EHU DEFINITION DATA SOURCES

The primary published data sources used in this study included:

1) Nautical Charts

2) U.S. Coast Pilots (Reference 6)

3) Corps of Engineers, Port Series (Reference 7)

4) Guide to Port Entry (Reference 8)

5) Jane's Freight Containers (Reference 9)

6) Tidal Current Charts (Reference 10)

7) Vessel Traffic Data - various ports (Reference 11-16)

8) Waterborne Commerce of the U.S. (Reference 17)

9) Data from the Marine Vessel Casualty Reporting (MVCR) System (Reference 1)

In addition to the published data sources listed above, a more extensive data collection was performed for the New Orleans port description. These data sources and their applications are outlined in the following paragraphs.

1975 Traffic Survey

Coast Guard radar films of a 1975 vessel traffic survey performed in New Orleans were obtained and used to establish vessel and trackline definition.

Direct Observation

Direct observation data collection was performed for two days at each of two observation sites and for three days at one observation site in New Orleans during September, 1979. The data obtained defined types and sizes of vessels, positions of the vessels in the channel, direction of travel and approximate speeds.

New Orleans VTS

Personnel at the VTS in New Orleans, La. provided information on preferred routes, reference track lines, river conditions, and maneuvering practices.

Interviews

Interviews were limited to informal discussions with working pilots and the civilian pilot attached to the New Orleans VTS. Contact with the pilots was primarily during vessel rides, when the opportunity to establish a dialogue with the pilot was best. During a ride, the observer could watch the actions of the pilot and discuss with him the reasons for these actions. Of particular importance was the information relating to the pilot's preferred route and his perception of the preferred routes and probable actions of other pilots on the river. This type of information was best obtained from the pilots in the immediate context of the decisions they were making on the bridge.

The representative track lines obtained from the radar traffic survey were compared with the track lines obtained from direct observation and the track lines determined from interviews with working pilots and the civilian pilot attached to the New Orleans VTS. All three data sources concurred on general traffic patterns. Differences within data sources and between data sources were regarded as normal variations in pilot preferences and vessel maneuvering characteristics.

5.3 PORT DESCRIPTION SYNTHESIS

The port description consists of preparing detailed descriptions of each EHU.

The major categories which define the EHU are:

Port Facilities Types and locations of the port facilities establish what parts of the harbor would be used by participating vessels and what types of vessels these would be.

EHU Structure EHUs are defined by shape and probable use.

Shoreline Characteristics Visibility in a port may be restricted by certain type of shorelines.

Waterway Characteristics The depths, location of channels, and sizes determine traffic patterns.

Aids to Navigation These establish traffic patterns and routes; also, restricted areas are defined.

Traffic Characteristics Traffic is characterized as opposing, following, merging, crossing and maneuvering.

Vessels The types of vessels and spatial distribution by type or class is established.

Cargo Cargo type and quantity establish traffic routes; hazardous cargos may require special rules.

Environment Information on tides and tidal currents, winds and factors affecting visibility such as fog, precipitation, etc. establish maneuvering characteristics.

6. SAFETY, CAPACITY AND COST COMPARISONS

To develop comparisons of safety, capacity and cost and the trade-offs among these, eleven port areas representing sections of the ports of New York, New Orleans, Houston/Galveston and Puget Sound were studied. Several simulations were exercised for each of these port areas with several types of traffic management techniques. Cost estimates were calculated for VTS utilizing these systems. The estimated costs do not necessarily reflect the actual costs of VTS which may presently exist in these ports.

6.1 COST ESTIMATION OF VARIOUS LEVELS OF TRAFFIC MANAGEMENT

Cost estimates for Vessel Traffic Services vary with the level of sophistication of the system installed and the size of the port. Also, for a given level of control, several traffic management approaches are possible and the system, hardware and operating personnel necessary to realize a traffic management approach may also be varied.

Cost estimates (in 1979 dollars) include research and development, acquisition, and installation costs, annual operating expenses, and total 15 year costs (discounted at 10% per year to 1975 present value) for several VTS systems which are representative of the range of system capabilities.

The costs for the system components are incremental. These cost estimates were taken from a U.S. Coast Guard statement to the Congressional Subcommittee on Coast Guard and Navigation (Reference 18). In addition to these costs, the statement also estimated incremental costs of $4.5 million to $6.5 million to provide "sophisticated" automated capabilities.

The total cost estimates obtained are provided in Table 6-1 for three levels of traffic control comprising the six traffic management techniques used in the simulation exercises in this study.

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LEVEL OF CONTROL	TRAFFIC MANAGEMENT TECHNIQUE	SYSTEM CONFIGURATION	TOTAL COST (MILLIONS OF DOLLARS)
LOW	TRAFFIC SEPARATION SCHEME	VMRS	6.6
	NAVIGATION ADVISORY	VMRS LLTV	8.9
MEDIUM	TRAFFIC WARNINGS	VMRS RADAR	9.2
	DEPARTURE/ ARRIVAL CONTROL	VMRS LLTV AUTOMATED DATA BASE	13.4
HIGH	CONFLICT RESOLUTION	VMRS RADAR AUTOMATED TRAFFIC ANALYSIS	15.7
	ROUTE/ SPEED ASSIGNMENT	VMRS, LLTV RADAR AUTOMATED TRAFFIC ANALYSIS	18.0

TABLE 6-1

TRAFFIC MANAGEMENT TECHNIQUE COST ESTIMATES

6.2 SAFETY, CAPACITY AND TRAFFIC MANAGEMENT COST RELATIONSHIPS

The safety and traffic measures described earlier in this report were calculated for the ports and the traffic management techniques described above. Selected results of the simulation are presented here.

Table 6-2 shows the number of encounters and very close encounters which occurred in a simulation run. These are given for the port areas and the traffic management approaches simulated. In addition, the ratio of encounters to very close encounters is also presented. This ratio identifies the proportion of times that an encounter (a normal occurrence) results in a very close encounter. The ratio can assume a magnitude between zero and one. Larger values correspond to more hazardous situations. The range of values obtained correlates with the calculated mass accident coefficient values. In eight of the eleven port areas, the use of traffic management reduced the ratio of total very close encounters to total encounters. In nine areas, the introduction of traffic management reduced the total number of very close encounters.

Table 6-3 presents the average vessel transit time over all vessels in a simulation exercise. The time in system is the time between when the vessel enters the simulated port area (enters the system) and when it leaves the port area (exits the system) and represents the transit time of the vessel. The average times are given for transits without and with traffic management. The first represents the time required for the vessel to transit under optimal conditions; that is, along its planned route at planned speeds. The second time shows the increase in transit time due to external influences. The increase of time in system is shown; these increases are regarded as insignificant when they are expressed as percentage increases as shown in Table 6-4. This table relates the percentage increase in time in system (average transit time) for the various levels of traffic management approaches.

The results of the capacity/traffic management trade-off suggest that traffic management approaches have little impact on the capacity of the ports at the traffic levels simulated. An effort was made to make the simulation scenarios representative of actual port conditions. The

TABLE 6-2

SAFETY MEASURE - RATIO OF VERY CLOSE ENCOUNTERS TO TOTAL ENCOUNTERS

6100

PORT AREA		HOUSTON SHIP CHANNEL-BOGGY & GREENS BAYOUS	HOUSTON SHIP CHANNEL-GALVESTON	HOUSTON SHIP CHANNEL-HOUSTON	NEW ORLEANS	NEW YORK-EAST RIVER	NEW YORK-LOWER BAY	NEW YORK-NEWARK BAY AND KILLS	NEW YORK SHOOTERS ISLAND AREA	NEW YORK-UPPER BAY	PUGET SOUND-ADMIRALTY INLET	PUGET SOUND-STRAIT OF JUAN DE FUCA
WITHOUT TRAFFIC MANAGEMENT	VERY CLOSE ENCOUNTERS	37	24	48	68	67	41	96	20	33	39	6
	TOTAL ENCOUNTERS	53	43	54	135	115	87	118	28	60	55	11
	VERY CLOSE ENCOUNTERS / TOTAL ENCOUNTERS	.698	.558	.889	.504	.583	.471	.814	.714	.550	.709	.545
WITH TRAFFIC MANAGEMENT	VERY CLOSE ENCOUNTERS	25	9	25	45	50	[illegible]	82	29	31	36	[illegible]
	TOTAL ENCOUNTERS	65	37	51	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	13
	VERY CLOSE ENCOUNTERS / TOTAL ENCOUNTERS	[illegible]	.243	.490	.296	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TABLE 6-3

AVERAGE TRANSIT TIMES

PORT AREA	TIME AVERAGE TRANSIT (MINUTES) WITHOUT TRAFFIC MANAGEMENT	TIME AVERAGE TRANSIT (MINUTES) WITH TRAFFIC MANAGEMENT	INCREASE IN TRANSIT TIME (MINUTES)
HOUSTON SHIP CHANNEL BOGGY & GREENS BAYOUS	33.0	34.6	1.6
HOUSTON SHIP CHANNEL GALVESTON	90.7	91.5	0.9
HOUSTON SHIP CHANNEL HOUSTON	34.0	34.7	0.7
NEW ORLEANS	128.0	136.7	8.7
NEW YORK EAST RIVER	63.0	69.5	6.6
NEW YORK LOWER BAY	90.7	92.7	2.0
NEW YORK NEWARK BAY & KILLS	48.1	51.1	1.0
NEW YORK SHOOTERS ISLAND	17.4	18.9	1.5
NEW YORK UPPER BAY	19.6	41.[illegible]	1.[illegible]
PUGET SOUND ADMIRALTY INLET	68.9	69.5	0.6
PUGET SOUND STRAIT OF JUAN DE FUCA	86.4	86.6	0.2

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TRAFFIC MANAGEMENT APPROACH: LEVEL	TRAFFIC MANAGEMENT APPROACH: TYPE	HOUSTON SHIP CHANNEL – BOGGY AND GREENS BAYOUS	HOUSTON SHIP CHANNEL – GALVESTON	HOUSTON SHIP CHANNEL – HOUSTON	NEW ORLEANS	NEW YORK EAST RIVER	NEW YORK LOWER BAY	NEW YORK NEWARK BAY AND [illegible]	NEW YORK SHOOTERS ISLAND	NEW YORK UPPER BAY	PUGET SOUND ADMIRALTY INLET	PUGET SOUND STRAIT OF JUAN DE FUCA	SYSTEM COST (MILLIONS)
LOW	TRAFFIC SEPARATION SCHEME										0.4%	0.7	8.66
	NAVIGATION ADVISORY				6.8%		1.[illegible]%						8.9
MEDIUM	TRAFFIC WARNINGS								8.6%				9.2
	DEPARTURE/ ARRIVAL CONTROL							6.7					11.4
HIGH	CONFLICT RESOLUTION			1.0%			10.4%						15.[illegible]
	ROUTE/ SPEED ASSIGNMENTS		4.8%		2.0%						1.8		18.0

TABLE 6-4

PERCENTAGE CHANGE OF TIME IN SYSTEM

conclusion is that capacity does not presently represent an important consideration in selecting a traffic management approach.

7. VESSEL TRAFFIC SIMULATION MODEL

7.1 MODEL SYSTEM OVERVIEW

The Vessel Traffic Simulation Model is composed of four separate computer programs linked together by data files. A summary of each program is provided in the following paragraphs.

Input Preparation Program

The Input Preparation Program reads, processes, and prepares the input data for use by the Ship Traffic Model. The input data consists of the following:

1) Harbor system layout
2) Reference track line system
3) Initial conditions, (speed, location, etc.) of each vessel
4) Maneuvering parameters of each vessel
5) Route information of each vessel
6) Simulation time limits

Following the organization and manipulation of the data, it is written to an output file that is the primary input to the Ship Traffic Model Program.

Ship Traffic Model Program

The Ship Traffic Model Program is a computerized model of a port. Simulated ships maneuver through the port along a series of reference track lines at specified offset distances from those reference track lines and at speeds which may vary for each track line in the ship's route. As the ship proceeds along its intended route, in a series of time steps, it will vary its speed and direction as it normally would

when transiting a port. A ship may move at a slow speed in a narrow waterway or when approaching its berth or anchorage, and at faster speeds in less restricted waters. The ship may deviate from its planned route, but must always remain within the fairway boundaries which are established for each particular class of vessel.

When a ship encounters another ship, or a fixed object, the model will maneuver the ship by altering its speed and/or course, so as to avoid the other ship or obstacle. The model uses a set of conflict resolution rules to establish the burdened and privileged vessels and determine the necessary maneuvers. The conflict resolution rules are derived from the International, Inland or Western Rivers Rules of the Road, or special requirements, depending on the area being simulated. The conflict resolution rules are described in the model by a local rules matrix. In each encounter situation, the definitions of safe distance, as well as minimum speed, are functions of the vessels involved. For example, safe passing distance is proportional to the lengths of the vessels involved and two small ships can pass at a closer distance than two large ships.

During a simulation, the model continuously searches for conflicts between vessels by examining the movements of other vessels about each vessel. When a vessel is not in conflict it continues normally along its preplanned route. When conflicts are detected, they are resolved through course and/or speed alterations. The search for conflicts is not unbounded, however. Each vessel has associated with it an area of observation. The model only looks for conflicts within this area. It is possible for two vessels to be in conflict and the model will not note this if the size of the area of observation has been made small. Also, in order to simulate situations where vessels sail close to one another but are not in conflict, such as in a narrow channel, vessels can be caused by the model logic to ignore one another when they are on different track lines.

The response of a vessel to a change in either course or speed is not instantaneous. The ship maneuvering logic includes second order

response functions to simulate the time delay which occurs when a change in speed or a new rudder angle is ordered and when the ship attains the desired speed or heading.

The physical characteristics which affect vessel maneuvering are also simulated. Harbor and fairway boundaries, shoals, and fixed objects are defined by specifying the reference track line system. In the model, ships sail parallel to reference track line segments at specified offset distances. A vessel will stay at the offset distance unless an encounter occurs. Depending on the situation, the vessel will then increase this distance to avoid a conflict. Maximum offset distances are specified for each reference track line segment and each vessel. This effectively defines the navigable waterway for each ship. Water current direction and speed may also be specified for each reference track line segment. Varying currents throughout the harbor can be defined. The effects of current are part of the ship maneuvering equations. Reduced visibility, due to resource obstructions, is simulated by adjusting the area of observation for a ship or by a decision logic matrix (part of the model) which permits ships on one track line to ignore those on another.

At each simulation time step, data is written to an output file. The simulation time and the number of vessels in the system is written to the file followed by data for each vessel:

1) Vessel identification
2) Position
3) Present reference track line
4) Heading, desired heading, reference heading, and rate of turn
5) Speed, desired speed, and acceleration or deceleration
6) Offset distance, desired offset distance, and boundary distance
7) Encounter indicators
8) Extreme maneuver indicators

The raw data from the Ship Traffic Model Program output file is prepared for analysis in an organized and systematic manner. The data is prepared in five parts by two computer programs discussed in the following paragraphs.

Output Analysis Program

The Output Analysis Program organizes and presents three sections of data. These are the event history, event summary and mass accident coefficient analysis. The event history records all events which occur during a simulation run. These events are:

1. Ship entering the system
2. Ship departing the system
3. Encounters
4. Very close encounters
5. Extreme maneuvers

Various details are printed in the event history for each event. The data associated with an event are specific to the particular event and permit a detailed evaluation of the circumstances surrounding it. The event summary provides cumulative data on the events identified above. In particular, the duration of each encounter and the ships involved are listed together with the total number of encounters. The same is done for very close encounters. The number of extreme maneuvers and "accidents" for each ship is also tallied. Finally, the mass accident coefficient is calculated for each simulation run. It is utilized as a measure of traffic management effectiveness and port safety.

Tabulated Data/Print Plot Program

This program organizes and presents two sections of data. These are the track history and track history plot. The track history is the fundamental form of output of the model. It is a list of the positions of all ships during the simulation run together with information such as ship identification, heading, rate of turn, speed and acceleration deceleration. This information is recorded for every time step in the simulation.

The track history plot is a graphic representation of the ships' track histories. The line printer prints, in graphic form, the position

of each ship at each step of the simulation run. In addition to the ship positions, the harbor boundaries and the reference track line system may also be displayed. This plot provides a visual aid to analyzing the results of a simulation run.

7.2 MODEL ENHANCEMENTS

The objectives of the model enhancements were to define, implement, and checkout modifications to the Vessel Traffic Simulation Model programs. Modifications were necessary for a more accurate simulation of the traffic and for associated problems specific to certain ports, particularly the Port of New Orleans. The modifications to the model are the following:

1) Towboat with tow maneuvering parameters
2) Conflict detection and resolution
3) Track-keeping
4) Stochastic variability

All of the software modifications are consistent with the original simulation model software development. The generality of the original program has been maintained and all modifications are either input changes or options that need not be invoked.

Towboat with Tow Maneuvering Parameters

Towboats with tows represent a large percentage of the traffic in certain port areas and are significant factors in navigation because of their maneuvering characteristics as well as total numbers. Data on the maneuvering characteristics of these vessels was virtually nonexistent and estimates of the salient parameters were required in order to model these vessels.

The values of the parameters for towboats with tows were initially estimated on the basis of parameters for similar vessels of

other types and theory of naval architecture (References 19, 20 and 21). The model was then exercised with these estimates. The simulated track histories were compared with observed actual track histories and the previous parameter estimates were re-evaluated and calibrated. By this iterative procedure, the values and curves for the required input parameter constants were determined.

Conflict Detection and Resolution

The primary objective of this effort was the modeling of procedures used to detect and resolve conflicts as dictated by local seamanship practices, customs, and rules specific to the Port of New Orleans. Pilots, based on experience and familiarity with the physical environment of the port and other pilots' practices, will not necessarily maneuver in accordance with the Rules of the Road.

Modifications to two sections of the model inputs were required to simulate local seamanship practices. First, the reference track line system which defines a vessel's route and relative position in the channel was developed to reflect local navigation practices for conflict detection and resolution. Two sets of reference track lines extending the full length of the simulated area were developed, one set for upbound vessels and one set for downbound vessels. In the Mississippi River, the deep draft channel meanders within the overall navigable channel and vessels, particularly towboats with tows, navigate from one side of the channel to the other in point and bend navigation maneuvers. It was necessary to represent these practices.

The second section of model that was altered to reflect local navigation practices is the local rules matrix. The local rules matrix specifies, for each pair of reference track lines, how a vessel on the first reference track line is to respond to a vessel on the second in the event of a conflict. Under the usual Rules of the Road, two vessels approaching a reference track line crossing from opposite directions would be privileged or burdened dependent upon their relative positions and headings. On the Mississippi River, the water current sometimes

limits the maneuvering capability of downbound vessels. As a result, downbound vessels are generally regarded as the privileged vessels at crossings regardless of the relative positions and headings of the conflict vessels. The local rules matrix developed for the New Orleans area reflects these considerations and has been implemented in the model.

Track-Keeping

The model originally operated under the condition that if a vessel deviates from its planned track or speed on a reference track line, then it will not return to the planned track or speed until a new reference track line is reached. Normally, this assumption is a reasonable one since, to the model, the new track is a safe one in situations such as in open waters, where there is plenty of maneuvering room. In a channel such as the Mississippi River, however, a return to the planned track may be desired. This type of vessel behavior can be expected if the vessels are trying to avoid bank effects, to sail on ranges, or to achieve proper positioning for channel related maneuvers. It is also assumed that a pilot will attempt to return to and maintain a vessel's most efficient speed.

The track-keeping logic was modified so that following conflict resolution a vessel will return to its planned track and/or speed unless another conflict situation involving that vessel is in progress. In addition, if a subject vessel is in conflict with two vessels, one requiring the subject vessel to modify its speed and the other requiring track deviation, the subject vessel will return to its planned track or speed if both conflicts are resolved.

Random Variability

Random variability has been introduced into three decision making modules of the model. The purpose is to simulate minor errors in vessel position and variances in piloting behavior. Random variability has been introduced to the following modules:

1) The vessel data module of the Input Preparation Program in order to randomly vary vessel entry time into the system.

2) The route following module of the Ship Traffic Model Program in order to randomly vary vessel decision time to initiating a planned course change.

3) The conflict resolution module of the Ship Traffic Model Program in order to randomly vary vessel decision time to initiating a conflict avoidance maneuver

7.3 MODEL TESTING AND VERIFICATION

A computer model which is intended to simulate real world events requires testing, verification and validation. Testing is the process of checking all inputs, algorithms and outputs of the computer programs, individually and as a whole, to assure that the programs work according to specification. The testing of the Vessel Traffic Simulation Model was accomplished during and after the development of the programs.

The verification of the model is the process assessing the accuracy of the generated output of the programs with respect to the events simulated. For the Vessel Traffic Simulation Model, verification consisted of demonstrating the simulated track histories would match real observed track histories, within acceptable tolerances, when the simulated conditions matched the real world conditions.

The final step, validation, which was beyond the scope of Vessel Traffic Management Study, consists of determining that the assumptions made in the design of the model apply to the problems to be studied. Since the Vessel Traffic Simulation Model was designed to evaluate traffic management techniques, the validity of the model can only be established when sufficient data from an operating VTS is available and comparisons can be made between predictions of traffic situations generated by the model and real world experience.

The verification of the Ship Traffic Model output was performed by ASEC's subcontractor, TNO in the Netherlands. The Dutch are conducting a program to upgrade Vessel Traffic Services in the Port of Rotterdam and have collected a set of data using the traffic surveillance radars presently operating in Rotterdam. Since this data was obtained expressly for the purpose of identifying vessel tracks, the TNO organization was able to apply it to the model verification.

The data collection process consisted of photographing the radar PPI displays at sixty second intervals. This process was performed for a period of six days with about one to two hours of observations each day. The times of observation were varied each day to obtain traffic samples from periods of moderate to heavy traffic. In addition to the radar data, observations were made to determine the types of vessels.

The model was run using input data prepared from the radar observation analysis with a simulation output time interval equal to the radar observation interval. The distance between the actual and the simulated vessel position was calculated for each vessel and position in time. The average distance difference was calculated for each vessel over its entire route and normalized to the total length of the vessel's route. A mean distance deviation of 2-5% was obtained from the resulting normalized values with most vessel deviations clustered about the mean. The larger deviations were primarily attributed to small patrol craft which exhibit erratic motions and to large vessels which sometimes stop and then back into docking areas.

In the absence of measurement data in a U.S. port, it was decided to exercise the simulation using an extended port area representing the Upper and Lower Bays of New York Harbor. This extended area also included parts of Kill Van Kull and the East River.

The simulated vessel traffic was divided into three groups. The first group, consisting of ten (10) vessels, was used to prepare detailed track line plots. The purpose was to demonstrate the capability of the model to simulate the maneuvering of vessels following planned routes at planned speeds. The second and third groups of data utilized higher

traffic densities, 35 vessels and 67 vessels respectively. The results of these two tests demonstrate the statistical capabilities of the traffic simulation model for analyzing traffic flow and traffic management problems at higher levels of traffic density.

7.4 SIMULATION OF ALTERNATIVE TRAFFIC MANAGEMENT TECHNIQUES

The model was exercised for two problems simulating alternative traffic management techniques - an alternating one-way traffic scheme and an area avoidance traffic management scheme. A baseline run with no traffic management was required for comparison purposes.

The simulation area was the section of the Mississippi River in the area of New Orleans between Mile 85 and Mile 101 above Head of Passes (AHP). Head of Passes is the beginning of the Mississippi River system in the Gulf of Mexico. This area includes three upbound/downbound reference track line crossings; and Algiers Bend region where precise maneuvering is required, was included. The section of the river selected for one-way traffic and area avoidance was the area between Mile 93 and Mile 95.5 AHP which includes Algiers Bend and one reference track line crossing.

The baseline run consisted of a total of 46 vessels entering the simulation area over a seven hour period. All aspects of the baseline simulation run reflected the river traffic data obtained by direct observations, pilot interviews, VTS personnel interviews and the USCG Data Collection Van radar films. No traffic management technique was implemented for the baseline run. The alternating one-way and area avoidance simulation runs utilized the same vessel class distribution, arrival time distribution, preferred track lines, and vessel speeds as the baseline run, except as modified by the alternative traffic management requirements.

The one-way traffic management scheme was implemented with an alternating two hour one-way traffic area 2.5 miles long. For the first, third and fifth two hour periods the traffic flow was in the upbound direction and during the second, fourth and sixth two hour periods the traffic flow was in the downbound direction. As a vessel approached the one-way area it was determined whether the traffic flow was in its direction and if so, whether the vessel could transit the one-way area before the traffic direction was to reverse. If the transit was not possible the vessel would be required to stop and wait in a queueing area (anchorage) until the one-way traffic flow was in the proper direction.

The number of very close encounters in the one-way area was reduced by 50% over the baseline run. The very close encounters that did occur in the one-way area consisted of overtakings. The number of very close encounters outside of the one-way area increased slightly over the baseline run. This increase is completely attributable to congestion associated with the queueing areas. The total transit delay time for the one-way scenario was 29.36 hours. This delay was primarily due to the nineteen vessels that were required to stop and wait for reversal of the one-way traffic flow.

The area avoidance traffic management scheme was implemented with the same 2.5 mile river section serving as the avoidance area. Specifically, interactions between downbound towboats with tows executing flanking maneuvers and upbound deep draft vessels requiring the deep draft channel were to be avoided. At either end of the avoidance area a vessel look ahead area of 3000 meters was defined. Upon entering the look ahead area a vessel would examine the traffic in the avoidance area and the opposite look ahead area and determine if there was another vessel in those areas that, in combination with itself, would present a hazardous situation in the avoidance area. If a hazardous situation was projected, the burdened vessel was required to decrease its speed to a level, and for a time period, sufficient to prevent the vessels meeting in the avoidance area.

The number of very close encounters in the avoidance area was reduced by [illegible] over the baseline run. The number of very close encounters outside of the avoidance area increased slightly over the baseline run indicating that congestion and overtaking encounters were increased in the look ahead areas. The total transit delay was increased by [illegible] hours.

7.5 ADVANTAGES

Simulation has several advantages for studying complex systems such as vessel traffic in a port. First, without sacrificing accuracy, only the variables of importance to the problem need to be considered. In the Vessel Traffic Simulation Model the major variables of interest are the characteristics of the vessels, harbor characteristics, vessel routes, and rules for conflict resolution (equivalent to rules of the road or navigational practices). Variables such as vessel wind loading or bank suction, for example, are not considered because the model is aimed at studying traffic characteristics and not the individual behavior of vessels.

A second advantage to simulation is that problems are easily repeated. Thus the model can be set up for a port and run several times varying only the initial conditions or inputs (such as the number of vessels or vessel arrival times). In this way a large number of nearly identical situations can be evaluated and compared.

The third advantage is flexibility. The Vessel Traffic Simulation Model can be set up to simulate a real world port as it exists or in any number of variations. Also, traffic management techniques, which may or may not exist in the port, can be simulated.

7.6 LIMITATIONS

The simulation modeling approach has two important limitations

which are common to simulation models in general. The first limitation is that time and computer requirements become prohibitive for very large problems. In order to determine the risk levels of a waterway under conditions of escalating traffic loads, a model which is sufficiently sophisticated for accurate representation of marine traffic will likely operate more slowly than the actual events. Second, the quality and reliability of the output generated by the model is dependent upon the quality and reliability of the model input. A poorly specified model may easily generate irrelevant or invalid information.

7.7 POTENTIAL

The Vessel Traffic Simulation Model developed in this study provides an analytical tool for evaluating the effectiveness of traffic management in improving port safety and for assessing the concomitant effects on traffic capacity. The model can be applied to any port or harbor under a variety of traffic loading conditions. The model incorporates a high level of flexibility. At one level, vessels can be entered into the system at various times and places throughout the port. It is only necessary to specify the vessel parameters and establish its route by selecting the necessary elements of the pre-established track line system. At a higher level, the entire port configuration can be altered. It is not necessary to change any of the model logic to accommodate varying port configurations. This also applies to traffic management. By changing certain input parameters, it is possible to simulate a variety of traffic management techniques.

Other variations in the simulation of vessel traffic would require some modification to the model's logic. The design of the computer programs, however follows a structured, top-down approach so that modifications to one part of the model will have little impact on others.

8. SUMMARY

8.1 REVIEW AND INTEGRATION OF MAJOR TOPICS

The work described in this report constituted an effort to define traffic hazard and port capacity, to establish a VTS data base methodology, identify traffic management techniques and measures of effectiveness, and to develop a means to calculate safety and capacity. The culmination of the effort was the Vessel Traffic Simulation Model.

The capacity of a port is defined in terms of its basic capacity or its practical capacity. Both definitions use the concept of effective domain, the area about a vessel which must remain free of other vessels or fixed objects. Basic capacity is the theoretical maximum number of vessels that a port can accommodate under ideal conditions so that the effective domains do not overlap. Practical capacity is the number of vessels a port can accommodate when the effective domains must be increased in size because of less than ideal conditions. The methods to calculate capacity used in the study produce practical capacity estimates.

Port capacity can be measured directly in terms of the density (number of ships per unit area) which can safely utilize a port or as the speed/time requirements for a vessel to transit a port both in the presence and absence of other traffic. Capacity can also be measured indirectly in terms of the number of conflicts experienced by a vessel due to congestion which affects its capability to effectively transit the port. Traffic capacity measures for these different, but not independent concepts, have been developed.

To evaluate the effectiveness of VTS in reducing the number of collisions, groundings and rammings, it is first necessary to identify, define and classify the hazards to safe navigation. This was accomplished by analyzing available casualty data. Two sources of casualty data were used: (1) the MVCR data base for four ports over a five year period; and (2) the accident data base compiled by the New York VTS Office for 1968-1977. Eight categories of hazards were defined.

Quantitative methods of assessing hazard potential in terms of the effects of hazards on the maneuvering of vessels under various conditions have been developed. The situations under which accidents occur and, importantly, in which vessels are forced to perform evasive maneuvers to avoid accidents, are measured using the model and the severity of hazards to navigation in restricted waters are quantified. The basic quantities to be measured are ship encounters, very close encounters, extreme maneuvers, and the ratio of very close encounters to encounters. The emphasis, in selecting these measurement techniques, has been on hazards which have adverse effects believed to be preventable by traffic management techniques. Generally, these encompass hazards created by topography, traffic, environment, regulations (inadequacies or violation), and aids to navigation (inadequacies). Hazards due to factors such as equipment failures are usually not included as contributing to VTS preventable accidents.

Eight traffic management techniques have been identified, defined and related to the VTS operating modes. The information requirements associated with the traffic management techniques have been identified. The various alternatives for surveillance, data processing, and procedures were described and the impact of the techniques on mariners and others considered. Finally a methodology for evaluating traffic management techniques and alternatives for specific ports was outlined.

The results presented in this report show that traffic management techniques have a significant impact on port safety as measured by the methodology developed and utilized herein. The risk potential for a vessel transiting a port was reduced by from 10% to 60% in simulation exercises depending on the port and traffic management alternative. The interpretation and validation of such reductions will require further statistical analysis.

A second measure of effectiveness, the ratio of encounters to very close encounters, showed similar results. Encounters represent normal meetings between vessels whereas very close encounters represent potentially hazardous situations. In the latter case, the separation distance between vessels in conflict is less than the established minimum

safe distance and the effective domains of each vessel overlap. The relative change in the ratios when traffic management was implemented can be interpreted as showing that the proportion of times that a conflict resulted in a potentially unsafe encounter was reduced by 20% to 60%, again depending on the port and traffic management approach utilized. Again, these results require further analysis and validation.

The results of the capacity measurements for all port areas indicate that the theoretical practical capacity of each port area is much greater than the volume of traffic simulated. The percentage change in capacity measurements in all cases is insignificant. This leads to the conclusion that traffic management in U.S. ports, regardless of the approach, will likely have little impact on the capacity of the port and should not be an important factor in selecting a traffic management alternative.

8.2 THE [illegible] OF SIMULATION MODELING AS A TOOL

Proper simulation modeling abstracts the essential components of a concept to provide an accurate representation of the situation being analyzed while avoiding unneccessary complexities which obscure the desired results with insignificant detail. These considerations are reflected in the Vessel Traffic Simulation Model which was designed to efficiently evaluate system concepts, traffic flow, safety and capacity in a defined port without overemphasis of less important factors.

The simulation approach has very definite advantages in studying these concepts. First, it has the advantage of producing a large amount of information which would require many years of intensive data collection to obtain otherwise. Second, data from the model can be generated under controlled conditions. Third, situations can be replicated with variations in the inputs so that the effects of alternative traffic management techniques can be compared without implementation costs and risks. Against these benefits, however, must be weighed the risk that an improper or unvalidated model may produce totally inappropriate data.

The Vessel Traffic Simulation Model developed in this study provides a capability for expanded evaluation of the effectiveness of traffic management's role in improving port safety and assessing the concomitant effects on traffic capacity. The model can be applied to any port or harbor configuration under a high level of flexibility. At one level, vessels can be entered into the system at various times and places throughout the port by means of model input alterations. It is only necessary to specify the vessel parameters and establish its route by selecting the necessary elements of the pre-established track line system. At a higher level the entire port configuration can be altered, again by performing only input alterations. It is not necessary to change any of the model logic to accommodate varying port configurations. The same flexibility applies to traffic management. By changing certain input parameters it is possible to simulate a variety of alternative traffic management techniques.

Other variations in the simulation of vessel traffic would require some modification to the model's logic. However, the design of the computer programs follows a structured top-down approach so that modifications to one module or section of the model will have little impact on others. This feature is especially important when alternatives to the Rules of the Road for defining the conflict resolution rules are desired. The conflict detection and resolution section of the model utilizes decision tables to analyze conflicts beeween vessels and select the correct vessel maneuvers. Other sections of the model, such as the helmsman, vessel dynamics and track keeping parts will not be affected by changes in the conflict detection and resolution section.

To summarize, the Vessel Traffic Simulation Model provides a viable means of simulating vessel traffic, analyzing conflict data and measuring safety, capacity and traffic management effectiveness. It is a flexible tool providing the researcher with a way to see the effects of changes in a port system on vessel traffic in a way that cannot be done with historical data.

8.3 RECOMMENDATIONS

The points presented in this section are based on the central recommendation that the Vessel Traffic Simulation Model should be regarded as a tool for future use by the Coast Guard rather than as an end in itself.

The Vessel Traffic Simulation Model was developed to evaluate traffic management techniques by analyzing the hazard potential and capacity of a port under various conditions. As such, it was designed to produce data of a statistical nature. This is the basic purpose of the model. However, the model can be extended to the study and analysis of specific problems of conflict resolution between two or more vessels. Since it is possible to replicate the basic conditions of the problem and vary factors such as maneuvering strategies, vessel spacing, route alteration, or other conflict control techniques, the model can be adapted to the following types of problems:

1) Evaluate alternate "crisis" traffic management strategies;

2) Assess impact of traffic management strategies in specific instances on other traffic;

3) Evaluate approaches to resolution of temporary traffic congestion conditions;

4) Study effects of and methods of minimizing the effects of temporary hazards to navigation;

5) Reconstruct circumstances surrounding actual accidents and evaluate methods which could have prevented them.

The model has been exercised using New Orleans for two traffic management schemes: one-way and area avoidance scenarios. It is recommended that work be continued in the area of alternative traffic management simulation. Although one-way and area avoidance traffic

management have been simulated, further alterations and refinements would be expected to produce the best trade-off between hazardous encounter situations on the one hand and transit delay times on the other. Other management scenarios that merit attention include the following:

1) Vessel separation standards
2) Encounter prediction/control
3) Emergency procedure development
4) Speed control
5) Vessel arrival/departure control
6) Alternate routing
7) Checkpoint control
8) Traffic segregation standards
9) Effects of increased traffic
10) Effects of altered vessel class distribution
11) Effects of new locks and facilities, bridge construction, dredging operations, etc.
12) Special/hazardous vessel precaution analysis

It is recommended that a uniform data collection system be established which would extract relevant data from the individual VTS data files. A data base, preferably automated, should be established at a central location and consistent data collection and reporting techniques implemented in each VTS.

The minimum data which should be collected at an operational VTS source includes:

1. Vessel position as a function of time. If a surveillance system, such as radar, is in place, this would take the form of vessel track histories; otherwise a route description showing time and position at check points would be established.

2. For each transit:
   - type of vessel
   - draft
   - size (length, beam)
3. Planned destination and route.

The recommendation for making the model more directly useful includes developing a procedures manual. A procedures manual would systematize data collection, analysis and input preparation for the model. The procedures manual would provide a complete description for the model user of what data to collect, how to collect it and organize it, how to set up a problem, and how to prepare the data and run the model.

It is recommended that the model be made easier to work with. Currently, the vessel input preparation process is cumbersome and time consuming. Development of an input generator would significantly streamline the input data preparation process. An input generator would involve setting up a file of vessels with their associated parameters and a file of routes in the port. All that would need to be specified are the class of vessel desired, the arrival time, the initial position and final destination point. The input generator would assign the vessel parameters and provide all route data, including initial speed and heading, based on the type of vessel and its initial position and final destination point. The vessel route file would fill in all of the necessary data for each reference track line constituting the vessels route based on vessels' preferred routes.

Although it is possible to utilize the model in its present form (i.e. as a batch processing computer system), it is extremely cumbersome to do so. A real time capability is recommended. This would permit the rapid alteration of parameters so that problems could be repeated with minor variations. It would also provide a capability for dynamic variations of traffic control during a simulation exercise. An interactive graphics display would be necessary for these purposes.

9. VESSEL TRAFFIC SERVICES MANAGEMENT STUDY REPORTS

DATE	ASECR REPORT NUMBER	TITLE	TOPIC
[illegible] Dec 77	ASECR 77-127	Interim Report No. 1	Definition of harbor and traffic characteristics.
[illegible] Jan 78	ASECR 78-1[illegible]	Interim Report No. 2	Identification and classification of hazards to navigation.
[illegible] Dec 77	ASECR 77-128	Interim Report No. 3	Definition of vessel separation requirements and traffic capacities.
[illegible] Jan 78	ASECR 78-1[illegible]	Interim Report No. 4	Definition of traffic management techniques, level of control and mode of operation.
[illegible] Apr 78	ASECR 78-10[illegible]	Interim Report No. 5	Definition of traffic and accident relationships and development of measures of effectiveness.
[illegible] Sep 78	ASECR 78-121	Interim Report No. 6	Development of techniques for calculating hazard potential.
[illegible] Sep 78	ASECR 78-124	Interim Report No. 7	Development of techniques for calculating port traffic capacity.
[illegible] Oct 78	ASECR 78-126	Interim Report No. 8	Description of the Vessel Traffic Simulation Model.
[illegible] Apr 80	ASECR 79-102	Interim Report No. 9	Calculation of hazard potential and safety using the Vessel Traffic Simulation Model.
17 Apr 79	ASECR 79-103	Interim Report No. 10	Calculation of port capacity using the Vessel Traffic Simulation Model.
20 Apr 79	ASECR 79-104	Interim Report No. 11	Measures of safety, capacity and mass-accident coefficient for six levels of control.
10 May 79	ASECR 79-105	Interim Report No. 12 Draft Final Report	Results of the simulation test.
27 Jul 79	ASECR 79-105	Final Report	Results of the Vessel Traffic Services Management Study.
15 Jan 80	ASECR 80-109	Model Calibration Interim Report	Description of the New Orleans data base; description of the model modification; model calibration.
26 May 80	ASECR 90-196	Test and Verification Final Report Vol. I	Results of the test and verification of the Vessel Traffic Simulation Model using the New Orleans data base.
		Vol. II	Supporting derivations, data, model inputs and outputs.
		Vol. III	Vessel Traffic Simulation Model program documentation.

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11. GLOSSARY OF TERMS

TERM	DEFINITION
Aid to Navigation	Any signal device external to a vessel specifically intended to assist a navigator to determine his position or safe course, or to warn him of dangers or obstructions to navigation.
Bank Effects	The bodily movement of a ship toward the near bank due to a decrease in pressure as a result of increased velocity of water past the hull in a restricted channel and an opposing force which forces the bow away from the bank due to the increase in the bow wave on the near side. This second effect occurs in a restricted channel especially one with steep banks, as the ship is moved bodily toward the near bank due to the first effect.
Basic Capacity	The level of vessel flow defined for ideal conditions under which the maximum amount of navigable water for a given harbor is utilized. This provides the capacity references baseline from which capacity degradation factors can be measured.
Closest Point of Approach	The shortest distance realized between two vessels as they pass near each other.
Conflict Resolution	The ability of the model to institute slight alterations in the planned courses of simulated vessels to avoid collisions, rammings, and groundings.
Dead Reckoning	The process by which a vessel's position is deduced or computed trigonometrically, with relation to a known point of departure.
Decision Logic Matrix	The set of rules used in the model to determine if a conflict exists and how it should be resolved. Also called a local rules matrix.

TERM	DEFINITION
Effective Domain	The clear area surrounding a marine vessel which other vessels avoid entering. Also known as ship domain and dynamic domain.
EHU	Elementary harbor unit. The basic unit in a harbor in which the shape, shoreline, waterway type, aids to navigation, traffic patterns, vessel types, and environmental characteristics are as uniform as possible. Six standard EHU types have been identified as follows: . EHU TYPE 1 - Open Water . EHU TYPE 2 - Natural Open Channel . EHU TYPE 3 - Natural Restricted Channel . EHU TYPE 4 - Dredged Open Channel . EHU TYPE 5 - Dredged Restricted Channel . EHU TYPE 6 - Restricted Passage
EHU Matrix	A checklist of all possible EHU elements that provides a systematic means of determining the EHU type.
Encounter	A meeting between two vessels in which a maneuver must be initiated by one of the vessels in order to avoid a conflict.
Extreme Maneuver	A situation in which a vessel is forced to maneuver at the extreme limit of its physical capability.
Fairway	The main traveled part of a waterway; a marine thoroughfare, sometimes protected by law.
Hazard	The cause of any undesired evasive maneuvers or the obstruction of any required evasive maneuvers.
Heading	The horizontal direction in which a ship actually points or heads at any instant, expressed in angular units from a reference direction.
Local Rules Matrix	See decision logic matrix.

TERM	DEFINITION
Mass Accident Coefficient	An empirically derived measure which relates the risk of accident of a vessel to its draft and mass for a given volume of traffic.
MCVR	Marine Vessel Casualty Reports
Offset Distance	The lateral distance between a vessel's actual path and the reference trackline that it is following.
Practical Capacity	The actual capacity level of a harbor which has been degraded from the Basic Capacity level due to vessel position uncertainty and vessel domain distribution limitations.
Range	Two or more objects in line; used as a guide to navigation.
Resource Obstructions	Man-made structures or objects which obstruct visual and/or electronic aids to navigation or communications. They may affect either shoreside surveillance or ships own aids to navigation as well as communications.
Restricted Waters	Portion of a waterway in which two vessels cannot pass or in which passing must be accomplished with extreme caution.
Rules of the Road	The international regulations for preventing collisions at sea, commonly called International Rules of the Road, and inland rules of the road to be followed by all vessels while navigating upon certain inland waters of the United States.
Ship Domain	See Effective Domain.
Simulation Logic	Use of the decision logic matrix by the model to resolve a conflict. Also referred to as model logic.
Track Lines	Straight line segments within harbor fairways representing the general path of vessels within that fairway. Track lines may be peculiar to certain vessel types.

TERM	DEFINITION
Traffic Separation Schemes	Shipping corridors marked by buoys which separate incoming from outgoing vessels or which separate vessel types. Traffic separation schemes are improperly referred to as sea lanes.
Very Close Encounter	A situation in which two vessels are in an encounter situation and the distance between them is less than a prescribed minimum.
Vessel	Any type of craft, except aircraft, which can be used for transportation across or through water.
VMRS	Vessel Movement Reporting System
VTC	Vessel Traffic Center
VTS	Vessel Traffic Services

FILME